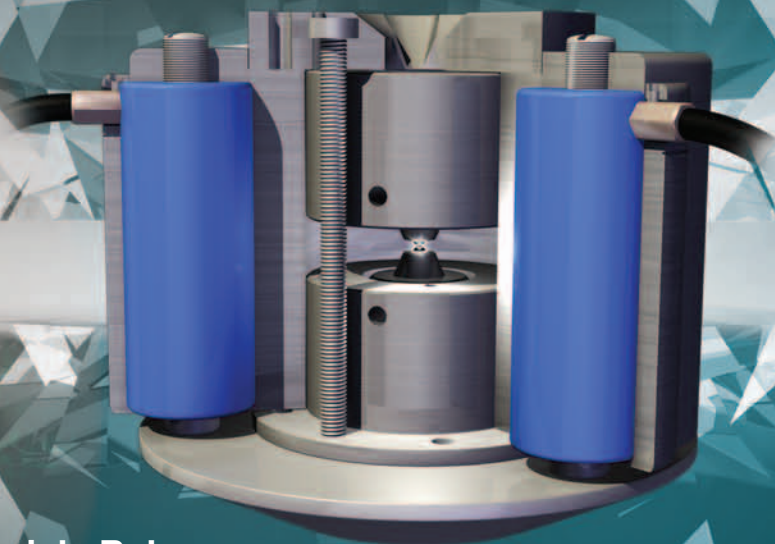


June 2010

Science & Technology

REVIEW

Squeezing Out the Details



Also in this issue:

A Look at How Granular Materials Behave
Portable Nuclear Magnetic Resonance
Optimizing Target Designs for Ignition

About the Cover

Research on materials under extremely high pressures, such as those occurring in a nuclear detonation, is critical to Livermore's national security mission. The article beginning on p. 4 describes two Laboratory techniques developed for such high-pressure experiments. On the cover is one of these technologies, the dynamic diamond anvil cell (top left image). With this device, researchers can control how quickly a material is compressed and thus study whether rapid pressure variations affect the material's microstructure and state. A rendering of the device (bottom right) shows the diamond anvils, which can hold samples up to 0.3 millimeters in diameter. In the background are a cutaway image of Earth's core (bottom left), where pressures range up to 360 gigapascals, and (top right) a microscopic view of an ice crystal, showing the treelike dendrites that form under some high-pressure conditions.



Cover design: Daniel Moore. Rendering: Kwei-Yu Chu.

About S&TR

At Lawrence Livermore National Laboratory, we focus on science and technology research to ensure our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published eight times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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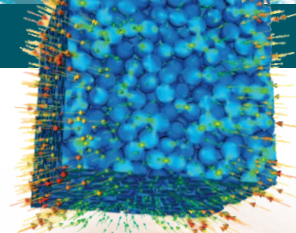
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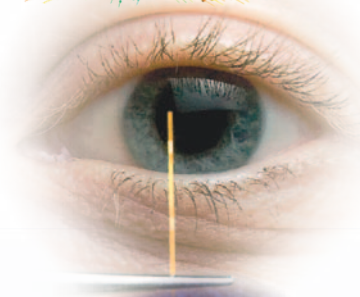


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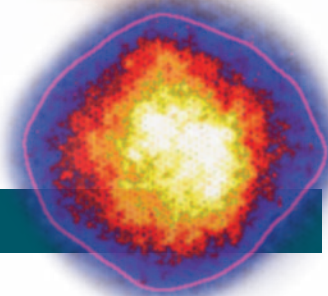
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Multilayer Mirrors Onboard Solar Dynamics Observatory

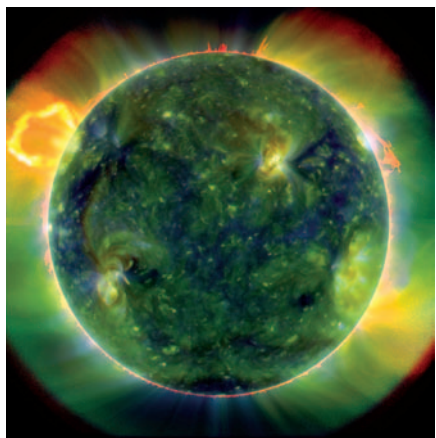
Multilayer mirrors developed by a Livermore team are part of the imaging instruments aboard the Solar Dynamics Observatory (SDO) spacecraft. Launched in February by the National Aeronautics and Space Administration (NASA), SDO has already produced stunning solar images in the extreme ultraviolet region of the spectrum, such as the one shown below. (More images are available online at sdo.gsfc.nasa.gov.)

Livermore researchers were pioneers in the development of multilayer thin-film coatings, which enabled extreme ultraviolet lithography (EUVL)—a technology designed for manufacturing improved computer chips. A Laboratory team led by Regina Soufli developed multilayer coatings for the mirrors used in two EUVL camera systems. Soufli's team adapted that same multilayer technology for the SDO Atmospheric Imaging Assembly, an array of four telescopes designed to provide an unprecedented view of the solar corona.

According to Soufli, developing the multilayer coatings for the telescope mirrors was no easy task.

Each of the four SDO telescopes contains a primary and secondary curved mirror. Two different reflective multilayer coatings must be deposited on these mirrors with a layer-thickness accuracy nearly equal to the diameter of an atom. Moreover, each coating must cover half of the mirror area, and masking off the point where the two coatings met was challenging. "We had to get the mask close to the mirror surface without touching it," says Soufli. "To minimize detrimental 'shadowing' effects on the area being coated, we shaped the mask edge using a special design."

SDO is NASA's most advanced solar mission to date. It records images of the Sun at 10 different wavelengths every 10 seconds, producing images whose resolution is 10 times greater than that produced on a high-definition television. SDO sends NASA about



1.5 trillion bytes of data per day, equivalent to downloading half a million songs every day—50 times more science data than any mission in NASA history. Results from this mission will help researchers better understand solar events such as sunspots, flares, and coronal mass ejections, which can affect air travel, the electric power grid, satellite communications, and astronaut safety.

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International Team Discovers Element 117

An international collaboration involving Lawrence Livermore has discovered element 117, the newest superheavy element. The team established the element's existence by observing decay patterns after a radioactive berkelium target was bombarded with calcium ions in the U400 cyclotron at the Joint Institute of Nuclear Research (JINR) in Dubna, Russia.

The two-year project began at Oak Ridge National Laboratory, where team members used the isotope production and separation facilities at the High Flux Isotope Reactor to produce berkelium samples for the experiments. Collaborators at the Research Institute for Advanced Reactors in Dimitrovgrad, Russia, prepared the targets, and experiments were conducted at JINR. Scientists from the Laboratory and JINR analyzed the data, and the entire collaboration, which included researchers from Vanderbilt University and the University of Nevada at Las Vegas, assessed the results.

The experiments produced six atoms of element 117. For each atom, the team observed the alpha decay from element 117 to 115 to 113 and so on until the nucleus fissioned, splitting into two lighter elements. (An animated video of the decay process is available online at publicaffairs.llnl.gov/news/video/2010/NR-10-04-02-video.html.)

Element 117 was the only missing element in row seven of the periodic table. The decay patterns observed in these experiments continue a trend of increasing stability for superheavy elements with increasing numbers of neutrons. This finding provides strong evidence for the existence of the so-called island of stability. Such an island would extend the periodic table to even heavier elements with longer isotopic lifetimes, which would enable advanced chemistry experiments. The team's research not only helps to expand scientific understanding of the universe but also provides important tests of nuclear theories.

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A Leader in High-Pressure Science

THE world we normally perceive consists of matter in a very narrow range of conditions: temperatures between 0 and 100°C, and pressures that do not vary far from the standard 1 atmosphere (100 kilopascals) found at sea level on an average day. Even in this limited slice of the universe, the simplest materials vary profoundly. Water is found in three completely different forms: solid, liquid, and gas. Carbon in the form of graphite becomes the prosaic material in our “lead” pencils, but it also takes the form of diamond, one of the most coveted gems. Plutonium can assume six different solid forms at normal pressures, in a very narrow range of temperature.

It turns out that this rich phenomenology of matter under “normal” conditions is only the proverbial tip of the iceberg. Deep within Earth, pressures are several millionfold higher than at sea level, and the interiors of giant planets in our solar system generate pressures higher by another factor of 10. Igniting inertial confinement fusion targets will achieve billions of atmospheres of pressure. At such high pressure, atoms can rearrange into new configurations and structures, and their electron clouds can interpenetrate, altering chemistry. Under the most extreme conditions, nuclei themselves interact to produce nuclear fusion and the exotic forms of matter found in neutron stars and quark–gluon plasmas.

At Lawrence Livermore, research on matter at high pressure is critical to many of our programs, including development of the U.S. nuclear deterrent and now science-based stockpile stewardship, treaty verification, and inertial confinement fusion. As a result, Livermore scientists are among the most distinguished in this research field. Major discoveries regarding the nature and behavior of elements from hydrogen to plutonium are attributed to fundamental high-pressure research at the Laboratory, pursued because of its importance to national security missions. In addition, basic high-pressure science at Livermore has led to many specific applications that benefit our core missions.

Recently, we applied our capabilities in high-pressure science to address questions about the “shelf-life” of plutonium pits in the nation’s nuclear weapons stockpile. The answer would determine whether these components must be replaced in the near future, at a cost of up to \$10 billion. Scientists combined experiments in diamond anvil cells at the Advanced Photon Source at Argonne National Laboratory with dynamic shock experiments at the Joint

Actinide Shock Physics Experimental Research Facility at the Nevada Test Site and theoretical calculations on the Laboratory’s BlueGene/L supercomputer. Results from this research helped demonstrate that new and aged plutonium behaved similarly enough at high pressure to alleviate concerns about aging components in the nation’s nuclear weapons stockpile.

The article beginning on p. 4 focuses on two new diamond anvil cell techniques that expand the frontiers of high-pressure science. The first is a “driven” cell that allows experiments to oscillate between the pressures of two phases—liquid and solid, for example—allowing researchers to observe how these phases interact. The technique provides insight into the physics of phase transitions, the way one phase grows from another as pressure increases. The second technique is a tool for studying how grain size—that is, the scale of inhomogeneities in crystalline materials—alters the effects produced by high pressure, an important issue for understanding the actual “rocks” that exist, for example, in Earth’s interior.


The stories told here are the tip of another iceberg—the great breadth of exciting, pioneering research on matter at extreme conditions that continues at Lawrence Livermore. On the big computers, scientists simulate the quantum mechanical behavior of hydrogen at extreme pressure and the way beryllium melts when shocked by an ignition pulse at the National Ignition Facility (NIF). Using the OMEGA laser at the University of Rochester, Livermore researchers measured the melting point of diamond at pressures found in planetary cores, studies that will be extended at NIF to the pressures found at the center of Jupiter, in the hope of understanding how planets form.

At the SLAC National Accelerator Laboratory, the first studies are under way with the Linac Coherent Light Source, which can directly observe how microstructure affects material response to high-pressure shock waves. Livermore scientists working at the Relativistic Heavy-Ion Collider are helping to unravel the mysteries of the early universe by developing models to simulate matter at the extreme conditions that occurred during the big bang. This broad scientific frontier is unified at Lawrence Livermore by our mission-driven need to understand at a fundamental level the way matter behaves at extreme conditions.

■ William H. Goldstein is associate director for Physical and Life Sciences.

Diamonds Put the Pressure

Novel capabilities in high-pressure pressures lead to dramatic changes



Livermore researchers have developed two new devices for studying materials under extremely high pressures. (above) The dynamic diamond anvil cell (dDAC) compresses micrometer-size samples between two brilliant-cut diamonds. (right) The moissanite anvil cell (MAC) uses larger moissanite (silicon carbide) anvils instead of diamond, allowing researchers to examine millimeter-size samples.

on Materials

*science are revealing how extreme
in material microstructures and phases.*

In nature, matter sometimes undergoes dramatic transformations that affect not only the state, or phase, of a material (changing it from gas to liquid to solid) but also its microscopic structure, or microstructure. For instance, when liquid water is boiled, it becomes a gas, but when frozen, it crystallizes. Even then, its microstructure can range from coarse-grained, as in a hard ice cube, to fine-grained, as in a “soft” Popsicle.

Just as temperature can change the state of matter, applying pressure can modify it as well. For example, one method to produce synthetic diamond uses high pressure and high temperature to transform carbon from the hexagonal structure of graphite into the hard diamond structure.

To examine materials under extreme pressures, Livermore scientists often use a device called a diamond anvil cell (DAC). (See *S&TR*, December 2004, pp. 4–11.) This small mechanical press forces together the tiny, flat tips of two flawless diamond anvils. As the diamond tips slowly compress a microgram sample of a material, they generate a fixed-pressure environment similar to that deep

inside Earth’s core, where pressure is up to 360 gigapascals (GPa), or 3.6 million times atmospheric pressure.

The material’s phase and microstructure are affected not only by the amount of pressure but also by the rate at which it is applied. Traditional DACs, however, do not allow researchers to change the speed of compression with any precision during an experiment. To study a material’s response to different compression rates, a team of Livermore researchers developed a new generation of DAC devices, called dynamic DACs (dDACs). With dDACs, scientists can control the compression rate by changing how quickly the anvils squeeze together or contract. “By varying the pressure, we can study how different rates induce microstructural changes in materials,” says Livermore physicist William Evans, who works in the Physical and Life Sciences Directorate and leads the dDAC team.

Another new device, called the moissanite anvil cell (MAC), allows researchers to examine larger material samples than they can study with DACs and dDACs. In a MAC, moissanite (silicon

carbide) anvils replace the diamond anvils in a DAC.

Together, the Livermore-developed technologies will improve scientific understanding of the processes that occur at extremely high pressures and temperatures, such as in a meteor impact, during a high-explosive detonation, or deep within a planet’s interior. Using these devices, researchers can develop advanced materials for new technologies and replicate specific phases and microstructures of synthetic superhard materials, such as diamond and cubic boron nitride, both of which are widely used as abrasives. Experiments at the Laboratory and the High Pressure Collaborative Access Team facility near Chicago, Illinois, are helping the team better understand how materials change at the microstructural level under a broad range of temperatures and pressures. (See the box on p. 6.)

Bridging the Knowledge Gap

According to Evans, high-pressure experimental science has traditionally been split between two approaches—dynamic and static. In dynamic, or shock,

experiments, a projectile accelerated by a laser or a gas- or explosive-driven gun impacts a sample. Scientists then measure the resulting wave of pressure and the speed of material particles accelerated by the impact to gather information about material properties under high pressures.

Shock experiments last no more than a few microseconds and can attain pressures up to several hundred gigapascals. Acquiring

data from these experiments is challenging, however, because the short, single-shot events produce extremely high temperatures, up to several thousand kelvins. Only a few diagnostic techniques can record results in this environment. (See *S&TR*, June 2009, pp. 22–23.)

In contrast, static experiments use opposing anvils to exert a fixed pressure on a material. The maximum pressure

achievable with this method is about 350 GPa, and temperature can range from less than 1 kelvin to a few thousand kelvins. Unlike dynamic experiments, static experiments typically last for several days and have no time limit for data collection. With fixed-pressure systems, a sample can be probed using various noninvasive techniques such as optical spectroscopy, electrical conductivity, and x-ray scattering.

A High-Tech Facility for High-Pressure Research

Scientists are interested in examining the structural evolution of pressure-induced phase transitions in materials because these processes occur in projectile and meteoritic impacts and can affect planetary models and industrial fabrication techniques. The x-ray capabilities available at the High Pressure Collaborative Access Team (HPCAT) facility allow them to rapidly collect data from diamond anvil cell (DAC) samples under extreme pressures and temperatures.

HPCAT is a multidisciplinary program established in 1998 with funding from the Department of Energy's National Nuclear Security Administration and Office of Basic Energy Sciences to integrate multiple synchrotron x-ray diffraction and x-ray spectroscopy probes

as well as complementary optical and electromagnetic probes. In addition to Livermore, HPCAT members include Carnegie Institution of Washington, Carnegie/Department of Energy Alliance Center, and University of Nevada's High Pressure Science and Engineering Center. The HPCAT facility opened to users in 2002 and is part of Argonne National Laboratory's Advanced Photon Source, located about 50 kilometers southwest of Chicago, Illinois.

"The HPCAT facility is specifically designed for high-pressure experiments with very tightly focused x-ray beams and instrumentation," says Livermore physicist William Evans. "It is the highest performance hard x-ray source in the U.S."

Evans and members of the Laboratory's High Pressure Physics Group are using the HPCAT facility to study phase transformations and the properties of materials over a broad range of pressure and temperature conditions. "The knowledge gained from our research will help us better understand material behavior at high pressures," says Evans. "Our results will provide a robust, high-fidelity experimental basis for predictive models of high-pressure systems including terrestrial structure and processes, planetary bodies, high-energy impacts, and advanced technological manufacturing processes."



The High Pressure Collaborative Access Team is one of many programs operating at Argonne National Laboratory's Advanced Photon Source, shown above. (Photo courtesy of Argonne National Laboratory.)

Dynamic and static experiments are complementary approaches. However, because the two techniques operate at different time scales and within different temperature ranges, their results are difficult to compare directly.

“The dynamic diamond anvil cell bridges the gap between static and dynamic experiments to address questions about how materials and microstructures transform and evolve at high pressures,” says Evans. “Very little has been published from experimental studies of these dynamic, pressure-induced transitions, and we know of no other groups in the world who have made an instrument that performs this way. The dynamic diamond anvil cell is an important advance for studying such a rich area of materials physics.”

Dynamic Diamond Device

Diamonds are an appealing material for use in anvil cells because they are the hardest known solid and can withstand ultrahigh pressures. In addition, a sample can be viewed through the diamonds and probed by x rays and visible light.

Fabricating a diamond anvil is a multistep process that generally begins with a brilliant-cut, 0.33-carat diamond consisting of 58 facets. The diamond must be free of inclusions or defects that could weaken it under pressure. At 100 GPa and above, diamonds occasionally shatter into dust. “However,” says Evans, “we usually try not to push them to this pressure limit, so we can reuse them multiple times.”

The tip of the diamond is polished until a flat surface, called a culet, is formed, providing a surface on which to place the sample. Although the culet appears round, examination under a microscope reveals that its face is actually an octagon. It takes this shape because the conical section of a cut diamond consists of facets, rather than a smooth cone, and the culet is formed by lopping off the end of the cone. For experiments below 50 GPa, the culet ranges from 0.1 to 0.5 millimeters in

diameter. For experiments above 50 GPa, it can be as small as 0.05 millimeters, and its sides are beveled downward to improve performance.

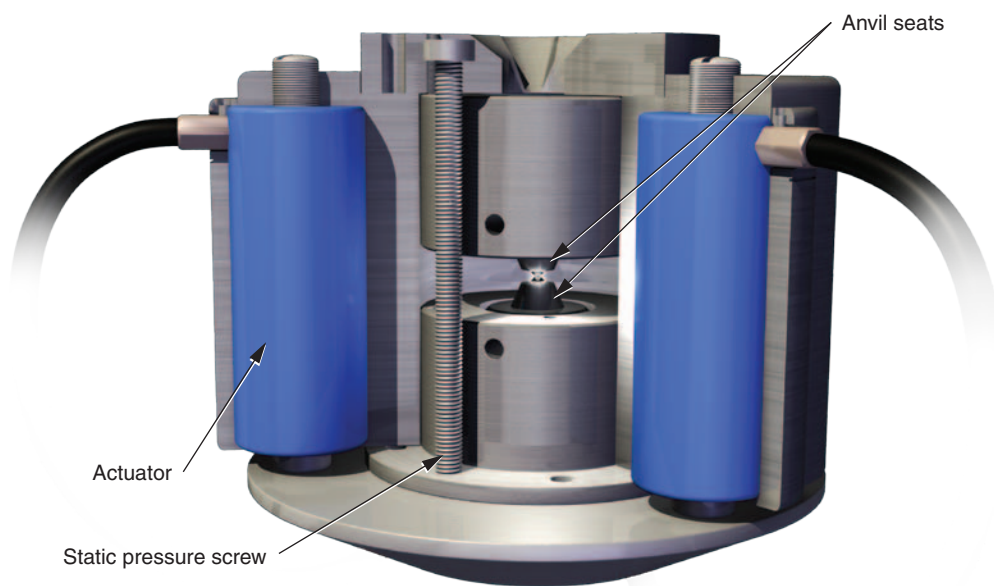
In a DAC, two diamonds are mounted in a cylinder that keeps the anvil tips aligned as the diamonds are driven together. Samples placed between the diamonds are held in place laterally by a gasket. The dDAC device enhances the basic DAC design by incorporating an electromechanical piezoelectric actuator that varies the pressure on the sample. The sample is first compressed under a fixed pressure. The actuator then applies an additional force that is either expansive (contracting) or compressive (squeezing together). “The electronic drive of the piezoelectric actuator permits precise changes in the pressure that we can reproduce multiple times,” says Evans. “In our experiments, we have shifted the pressure by as much as 50 percent of the initial fixed pressure and have achieved compression rates of up to 500 GPa per second, or 5 GPa in 10 milliseconds.”

A typical dDAC sample is about 300 micrometers in diameter, or about 3 times the diameter of a human hair. As the device compresses and decompresses a sample, researchers measure changes in the material’s microstructure and thermodynamic state. A video camera capturing 2,000 frames per second records the pressure-induced melting or freezing of the material.

The dDAC project, which began in 2005, is funded by the Science Campaign of the National Nuclear Security Administration. Key contributors include two former Livermore scientists: Choong-Shik Yoo, now a professor at Washington State University, and Geun Woo Lee, now a researcher at the Korean Research Institute of Standards and Science.

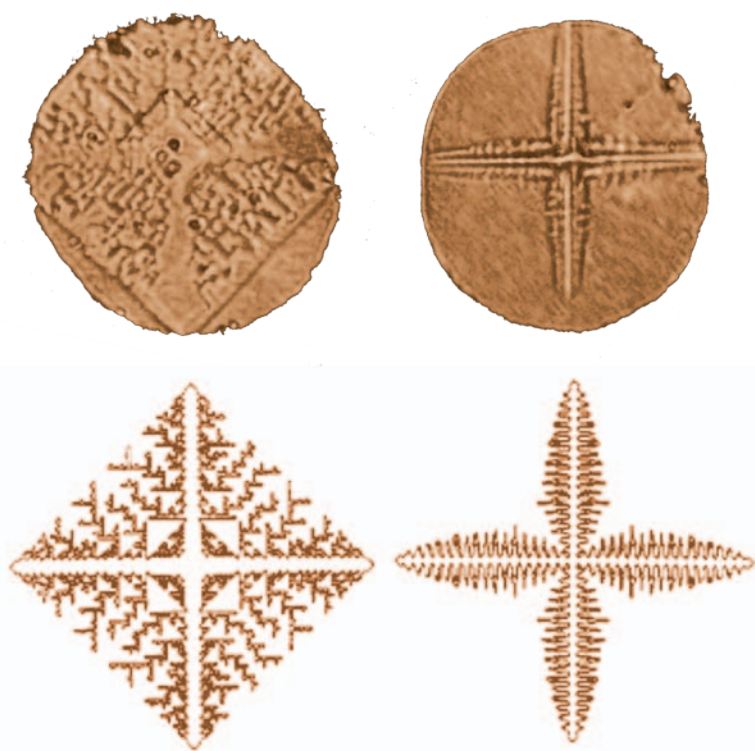
Crystal-Clear Water

Using the control mechanisms on dDAC, researchers can adjust the pressure and temperature in experiments and thus transform material samples into metastable phases. For example, water that



This diagram shows the setup for a dDAC device. As diamond anvils compress micrometer-size samples, the piezoelectric actuator varies the static pressure, allowing researchers to examine how compression rate affects material behavior. (Rendering by Kwei-Yu Chu.)

Microphotographic images of pressure-induced dendritic crystals (top row) are remarkably similar to the patterns produced in computer simulations of temperature-driven dendritic crystal growth (bottom row).



is supercooled can remain in liquid form at below-freezing temperatures until an external disturbance, such as a vibration or a seed particle, causes the solid ice phase to form.

The dDAC research shows that a material can also be superpressurized and will remain liquid beyond pressures that would typically transform it into a solid. In addition, liquid water can crystallize into unexpected metastable structures that are not observed under atmospheric pressures.

“Using dDAC, we can directly observe pressure-induced crystal growth and study how the compression rate influences morphology and growth mechanisms,” Evans says. “Traditionally, crystal growth has been studied from the thermal perspective by varying the temperature or the cooling rate. The dDAC device permits an analogous approach with pressure.”

In a dDAC study of water, the Livermore team found that different crystallization processes take place depending on the compression rate. At room temperature and thermodynamic

equilibrium, water solidifies at 0.9 GPa into the ice-VI structure (a tetragonal crystal structure in which two of the three crystallographic axes are equal in length, and all are at 90-degree angles). When pressure increases to 2.2 GPa, water transforms to ice-VII (a cubic crystal structure with three axes of equal lengths, all with 90-degree angles). Both of these structures differ from the familiar hexagonal structure of an ice cube at normal atmospheric pressure.

However, when the compression rate is greater than 0.08 GPa per second, water maintains its liquid phase up to 1.8 GPa, well beyond the 0.9-GPa transformation point. Even more surprising, the team found that the supercompressed water crystallized into the ice-VII structure while still in the thermodynamic stability field of ice-VI. “This finding suggests that compression rates may cause other metastable ice phases to form,” says Evans. “Clearly, further investigation is needed to fully understand the phase

transformation and stability of molecular fluids and solids.”

Crystal growth is an area of science where dDAC could make an important contribution, according to Evans. High-speed videos of crystals growing in water showed dramatic changes in the morphology and rate of growth as the compression rate changed. A faceted crystal formed at slow compression. However, when the rate increased to approximately 120 GPa per second, the growth patterns resembled multi-branching, treelike dendrites. Surface instabilities also appeared, which led to extremely rapid crystal growth.

Sometimes Size Matters

Although many high-pressure studies can be performed with dDACs, the small size of the diamond anvil limits the size of samples that can be examined. “We can’t study large samples with dDACs,” says Livermore geophysicist Dan Farber. “We may only be able to look at a few crystalline grains from a test material. Such small samples aren’t effective if the property we want to study is dependent on grain size.”

To meet this challenge, Farber is leading a team of five researchers in the Laboratory’s Physical and Life Sciences Directorate to develop MACs. The moissanite anvils for a MAC are 6 carats each and can hold samples as large as 3 millimeters in diameter compared with the 0.1- to 0.3-millimeter samples that a dDAC can compress.

Synthetic single-crystal moissanite is an ideal anvil material because of its high hardness and excellent optical properties (for example, it is transparent to visible light). The moissanite crystals used by Farber’s team are manufactured outside the Laboratory at a fraction of the cost for similar-sized diamonds. They are not faceted like the dDAC anvils but are conical, and the culet of the moissanite anvils can be fashioned to a near circle.

MACs can test samples with grain sizes larger than 10 micrometers and materials such as plutonium that are extremely difficult to handle in microscopic sizes. The MAC development project, which began in 2006, is funded by the National Nuclear Security Administration. In one MAC experiment, Farber, Livermore scientist Adam Schwartz, and their colleagues pressurized a sample of plutonium and examined the sample's microstructure using the Laboratory's transmission electron microscope. Results showed different morphologies for a phase of plutonium

formed under high pressure and the same phase formed by reducing temperature.

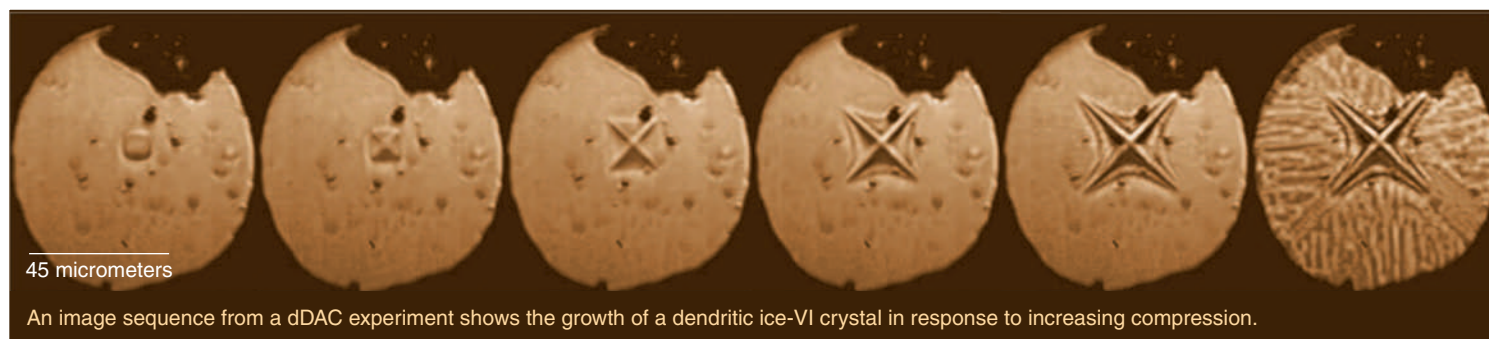
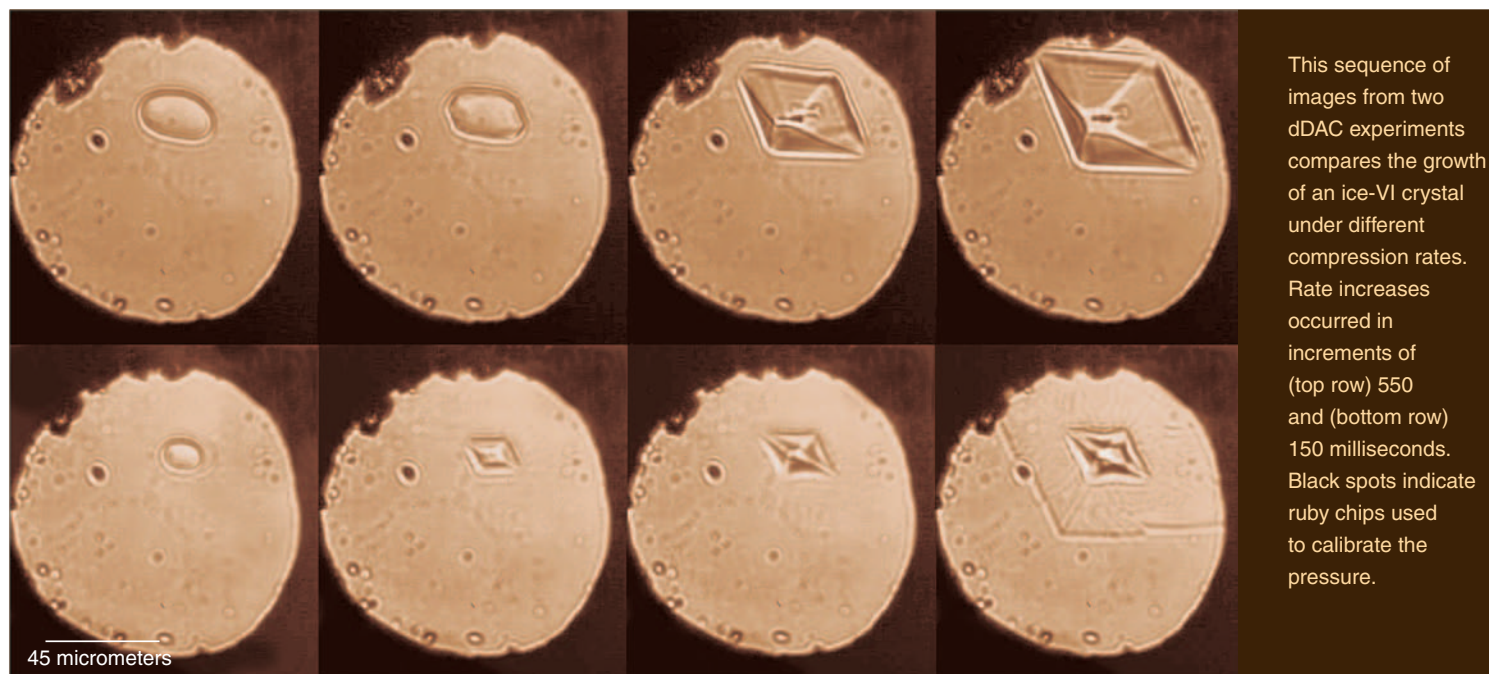
Although MACs are in the same family of research instruments as dDACs, they are not nearly as dynamic. Says Farber, "We can vary the rate of pressure with a MAC but not as quickly as we can with a dDAC." Instead, the team compresses a sample hydrostatically, using a range of pressure-transmitting materials, to create a uniformly pressurized environment that encloses the sample.

In general, MACs cannot withstand pressures as high as those applied by

dDACs. The Livermore MAC device has achieved a maximum pressure of 5 GPa, while diamond anvils can reach nearly 70 times that pressure. "The classic problem is that we can't generate high pressures and temperatures with MACs like we can with dDACs," says Farber. "On the other hand, although we can vary pressures dynamically with dDACs, we can't look at large samples."

High Potential at High Pressures

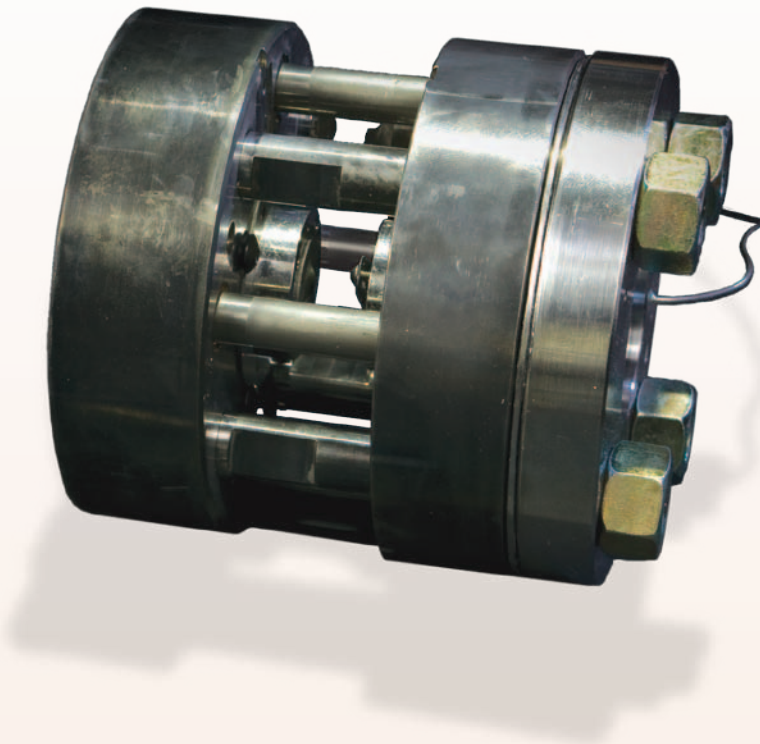
Understanding how material properties change as a function of pressure and



temperature is important to various science and technology efforts. Recent advances in high-pressure science at Livermore provide insights about subsurface planetary dynamics. Modeling the processes that occur at a planet's core cannot proceed without knowledge of material properties

at extreme pressure. In addition, new capabilities in high-pressure manufacturing may allow developers to precisely control microstructure to produce materials that are superhard, provide enhanced structural support, or improve optical communication.

The moissanite anvils for a MAC are 6 carats each and can hold samples up to 3 millimeters in diameter compared with the 0.1- to 0.3-millimeter-diameter samples that a dDAC can compress.



Preliminary studies using dDACs and MACs have already demonstrated significant progress, and according to Evans, this work is just beginning to reveal the potential of the two devices. "In the future, we will address a wide range of topics such as phase transformation kinetics and loading-rate-dependent phenomena," he says.

Farber adds that each technique has its limits. However, he says, "Using both instruments will allow us to investigate material strength and phase transitions in a way that couldn't be done before."

—Kristen Light

Key Words: compression rate, crystal growth, dynamic diamond anvil cell (dDAC), high-pressure experiment, material dynamics, moissanite anvil cell (MAC), phase transformation kinetics, static experiment, superhard material.

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Exploring the Unusual Behavior of Granular Materials

TRYP pushing a pencil through a block of Jell-O, and it penetrates the substance with relative ease. But push that pencil into a bucket of sand, and the farther it goes, the more resistance it encounters. What causes this difference? Friction between the particles strongly affects the behavior of granular materials, such as sand. As a result, these materials respond differently to external forces than liquids, solids, or gases do. This unique attribute—one of many—makes it difficult to predict their flow and mechanical behaviors.

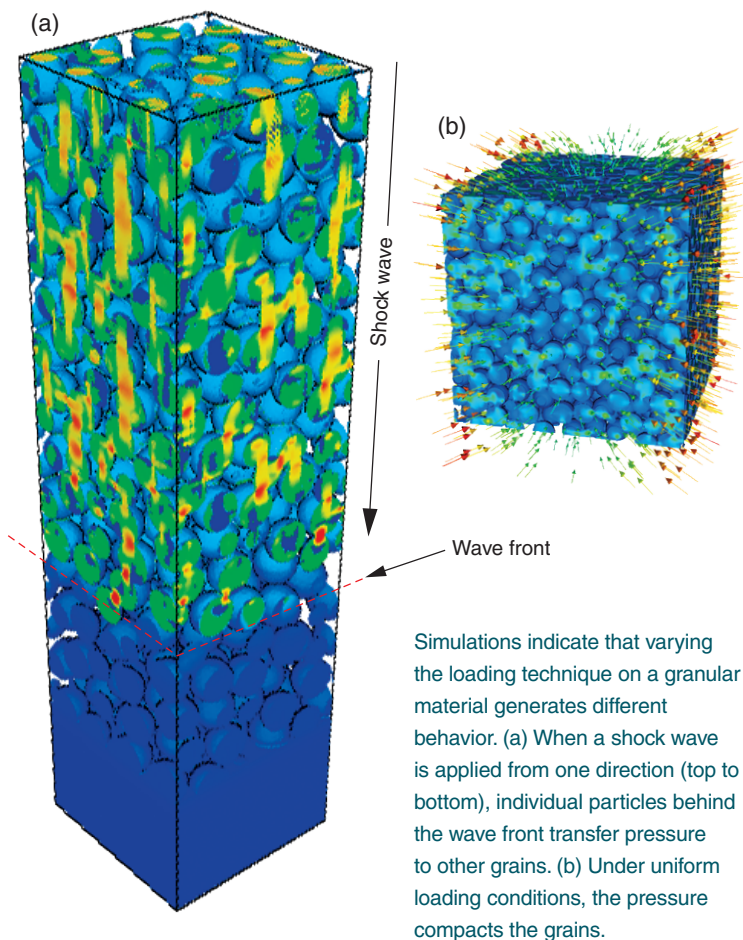
Granular materials stand in a class of their own, separate from other states of matter. Their behavior includes aspects of fluid and solid mechanics and molecular dynamics, but some responses are specific to them. In addition, properties that appear in the bulk material may not be exhibited by individual grains. To better understand these responses, scientists at Lawrence Livermore are developing predictive models to study granular materials under dynamic pressure loads so they can analyze material behavior at multiple scales, from the nanometer scale of grain–grain interactions up to the macroscale flow in a large conglomeration of particles.

“The Laboratory’s expertise in experimental science, materials research, and high-performance computing makes us particularly qualified to take on this challenge,” says Livermore physicist Tarabay Antoun, who leads the project team. The research effort, which is funded jointly by the Departments of Energy, Defense, and Homeland Security, will provide new modeling capabilities for use in many areas, from pharmaceuticals and agriculture to national security and defense. For example, the Livermore team is applying these models to help develop transparent ceramic armor for military vehicles. The research can also be adapted to study wave propagation in heterogeneous geologic materials and reactive transport processes in porous media such as soils and rocks. Understanding how fluids flow through porous media is vital to various research areas, including carbon sequestration and efforts to protect critical infrastructures from the threat of an earthquake or a terrorist attack.

Taking a Closer Look

Granular materials vary widely in shape, size, and physical properties. The Livermore research is primarily focused on granular powders, which have the smallest particle sizes. Powders consisting of brittle materials are of particular interest because individual particles can fracture and fragment when compressed, making the material’s overall response more difficult to predict. According to Antoun, the Laboratory team is combining experiments and

(left) As a shock wave propagates through a powder, individual grains (black dots) fracture and fragment, producing localized cracks (red lines) in the grains. Colors indicate the progression of damage, with red being the most severe.



modeling to examine brittle material powders under dynamic loading and determine how changes in stress and strain are related to fracture and fragmentation processes.

Current computer codes used to model granular materials are based on empirical relationships derived from experimental data and do not explicitly account for characteristics such as particle size and morphology. These models consider powder as a continuous medium rather than as a conglomerate of discrete particles. As a result, continuum models cannot capture the grain-scale processes affecting material response, such as how each particle transmits loads to the particles surrounding it.

“We need to understand compaction behavior in a wide range of particle sizes,” says Antoun. “For example, continuum mechanics does not apply to particles at the nanometer scale. Our goal is to develop predictive models that incorporate morphology and material properties so we can explore the physics of material response at levels well below the continuum scale.” Using these different methods, the team will be able to simulate material behavior over length and time scales that span several orders of magnitude.

Sophisticated instruments such as atomic force microscopes will measure the strain rate and fracture properties on individual grains of a material. The team will also perform shock compression experiments to characterize materials under dynamic loading. Results from these experiments will then be incorporated in the refined models along with first-principles calculations that are based solely on the fundamental laws of physics. Complex algorithms will calculate properties such as particle size and shape, and adaptive mesh refinement techniques will continually refine individual grid points as the simulation progresses, so that computational resources are used more efficiently.

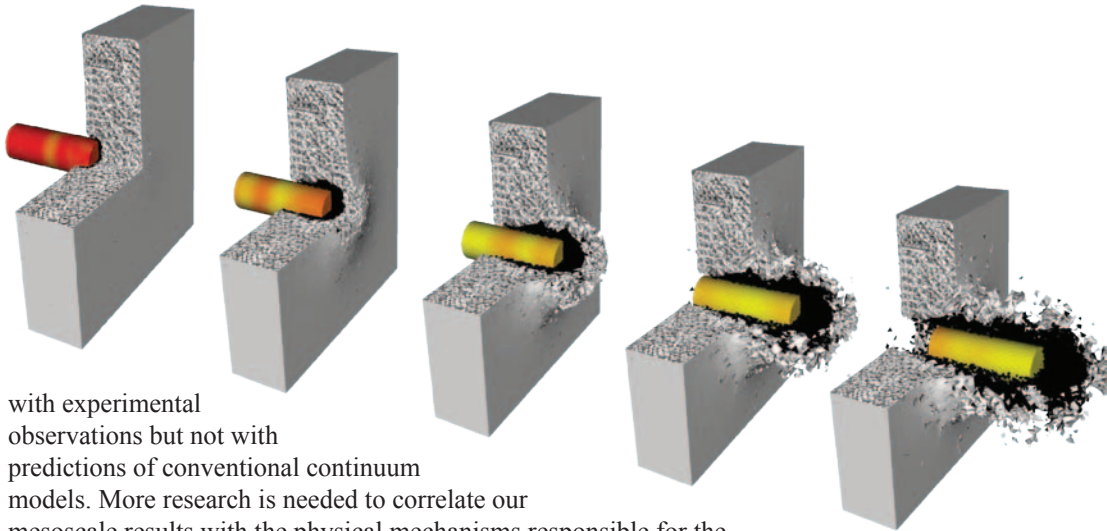
Nano- and microscale simulations will provide information about fracture behavior within individual grains, allowing researchers to visualize processes that they cannot easily observe in experiments. Mesoscale simulations resolve details within 1 millimeter, the same scale achieved in experiments. The team can thus directly compare modeling results with experimental data to validate the codes. Ultimately, the team will develop a macroscale continuum model that incorporates the essential physics of material response at the most basic level. “Our approach to a predictive continuum model is top down,” says Antoun. “We’ll begin by modeling the material at the macroscale, then progress to the lower scales as needed to gather fundamental information for further refining our macroscale model.”

Thus far, the researchers have focused on selecting and characterizing materials and conducting static and dynamic experiments. Their initial simulations are examining powders made of ductile materials, which have a less complicated response than those made of brittle materials. These models will allow the researchers to generate baseline data and test the codes’ overall effectiveness. Simulations of brittle materials will begin in the second year of this three-year project.

Protection at Home and Abroad

Antoun and his colleagues are already working on a variety of applications for the models. With funding from the Department of Homeland Security, they are building detailed models to simulate how rocks and soils will respond to loads generated by seismic events or explosives. “Granular materials are not only pressure sensitive,” says Antoun, “but they also behave differently depending on whether they are wet or dry, which influences the effective pressure.” Predicting how Earth materials and structures respond to pressure is important to protect vulnerable infrastructure and to develop strategies for mitigating damage from a potential earthquake or terrorist attack.

In a project funded by the Department of Defense, the team is working with researchers at Purdue University to examine how objects penetrate sand under dry and saturated conditions. “Our mesoscale model indicates that wet sand is easier to penetrate than dry sand,” says Antoun. “This result is intriguing because it agrees



Snapshots from a simulation show a projectile hitting a plate of transparent ceramic armor. As the object moves through the armor, the material turns into a granular powder (black) around the impact zone.

with experimental observations but not with predictions of conventional continuum models. More research is needed to correlate our mesoscale results with the physical mechanisms responsible for the observed behavior.”

Modeling granular materials could also help protect military vehicles. Transparent ceramic armor—a heavy, see-through material mounted as a protective windshield on tanks and other vehicles—behaves like a granular material when hit by a projectile such as a bullet, radiating pressure away from the damaged area. “With computational models, we can see in exquisite detail how a bullet affects the armor,” says Antoun.

Transparent ceramic armor is built to conform to many specifications. It must withstand extreme temperature variations, transmit infrared light for night-vision equipment, and withstand gunfire, making it notoriously difficult to develop. By advancing

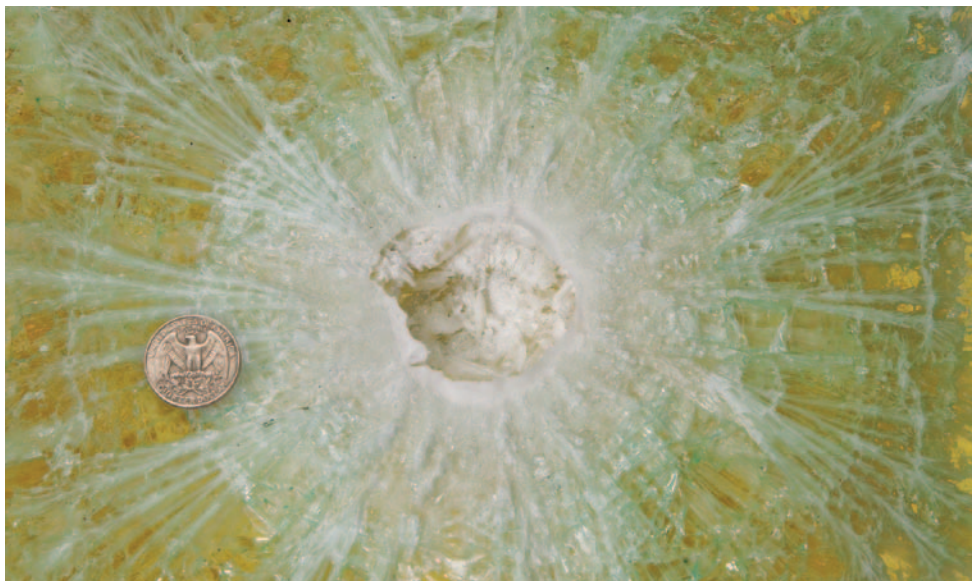
predictive capabilities for granular materials, Antoun hopes to significantly reduce the time and cost required to produce the next generation of transparent ceramics.

The Power of Supercomputers

“Granular materials have never been studied with the kind of detail we are working to achieve,” says Antoun. Until the last decade, computing technology was not advanced enough to simulate materials in three dimensions, especially at the small scales of interest to the Livermore team. Extremely powerful computers, such as those at Lawrence Livermore, are needed to perform calculations at such detailed resolutions.

“Through the Laboratory’s Computing Grand Challenge Program, we received 500,000 hours of computing time a week on BlueGene/L for our research,” says Antoun. With this resource, the team will be able to peer into the fundamental physics of granular material response and examine the intricate interactions between individual grains—paving the way for exciting advances in materials science.

—Caryn Meissner



When a projectile penetrates transparent ceramic armor, damage radiates from the entry point outward, creating an intricate web of cracks within the material.

Key Words: BlueGene/L, Computing Grand Challenge Program, continuum scale, granular material, multiscale predictive modeling, simulation, transparent ceramic armor.

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A 1-Ton Device in a Briefcase

NUCLEAR magnetic resonance (NMR) spectrometry is known for its ability to rapidly identify chemicals. Because this technique does not compromise the sample, the sample's properties remain intact for additional testing. A typical NMR spectrometer, however, weighs a ton and occupies an entire laboratory. A research team from Livermore's Physical and Life Sciences Directorate has revamped the technology so that it weighs a mere 9 kilograms (20 pounds) and fits inside a briefcase. The new device can be transported into the field for

on-the-spot analysis of potential chemical warfare agents or other hazardous chemicals.

NMR spectrometry measures how nuclei move in a magnetic field. Electromagnetic pulses generated by the spectrometer move through a sample, and the material's nuclei are "excited," absorbing energy from the pulse and subsequently radiating energy back out. Changes in the resonant frequency of each nucleus due to the surrounding electrons provide a fingerprint that distinguishes different molecular structures, making NMR spectrometry a

A portable nuclear magnetic resonance (NMR) device developed at Livermore fits inside a briefcase. Members of the development team (from left) Lee Evans, Joana Diekman, Kristl Adams, and team lead Julie Herberg display the new device next to a laboratory-scale NMR spectrometer.



powerful tool that is used extensively for chemical, material, biological, and medical applications. Separation techniques such as liquid chromatography and capillary electrophoresis are routinely coupled with an NMR analysis to supply additional information about a sample. Together, these tools can separate, unambiguously identify, and provide structural information about samples in small volumes.

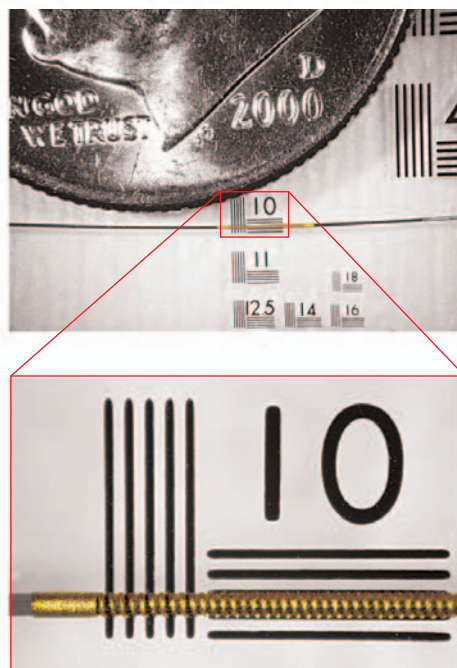
When Time Is of the Essence

The portable NMR device, which was developed with funding from the National Nuclear Security Administration's Office of Nonproliferation Research and Development, can identify the signatures of chemical and biological weapons, narcotics, explosives, toxins, and poisons. "At the moment, we are focusing on chemical agents, typically in very small quantities," says Livermore physicist Julie Herberg, who leads the portable NMR development team. "These agents are usually oils that decompose in a short time, so responders need a tool in the field that can evaluate substances quickly." She notes that mass spectrometry, which measures the mass of individual ions, can identify chemical agents more quickly but with less specificity than NMR.

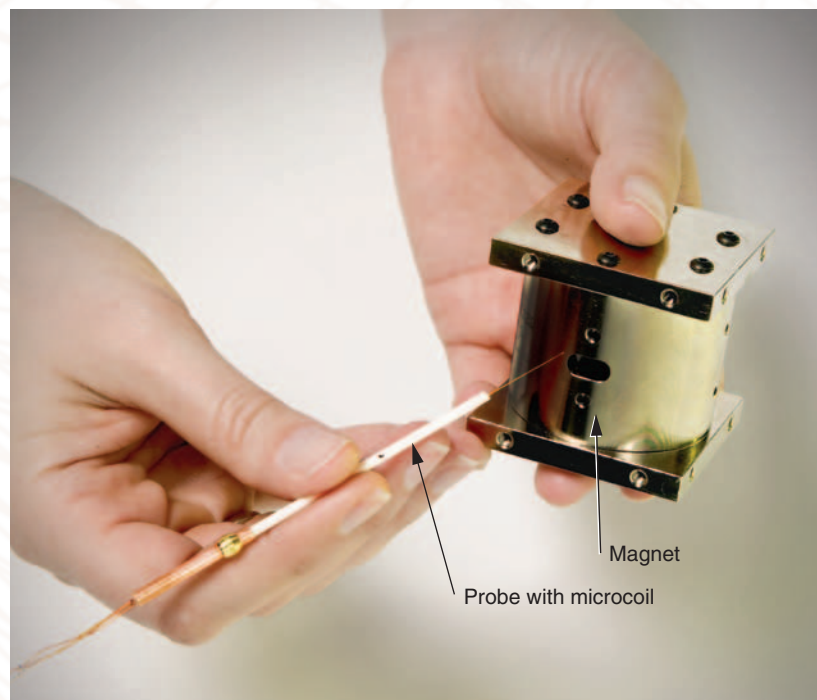
A typical NMR spectrometer requires huge superconducting magnets that are cooled with liquid nitrogen. Livermore's briefcase-size device operates on the same principles as the laboratory-scale machine, but it has a small permanent magnet that does not require cooling.

In the portable NMR briefcase, samples are introduced to the system through tiny capillaries. Three-dimensional lithographic and laser-cutting techniques combine to etch micrometer-scale coils on the capillary wall. "Other research groups are developing small NMR instruments," says Herberg, "but the coils on those machines are typically hand-wound, which limits the coil size, configuration, and reproducibility." In contrast, a Livermore-designed technique called LaserLathe can be programmed to repeatedly produce the miniature helical radio-frequency coils that are at the heart of any magnetic resonance system. The LaserLathe can fabricate radio-frequency coils with adjustable widths and line spacings on tiny capillary tubes ranging from 0.1 to 1.3 millimeters in diameter. A lithography-on-cylinder technology, LaserLathe is also used to produce heating wires around hohlraums for fusion experiments at the National Ignition Facility and coils for guide catheters in magnetic resonance imaging procedures.

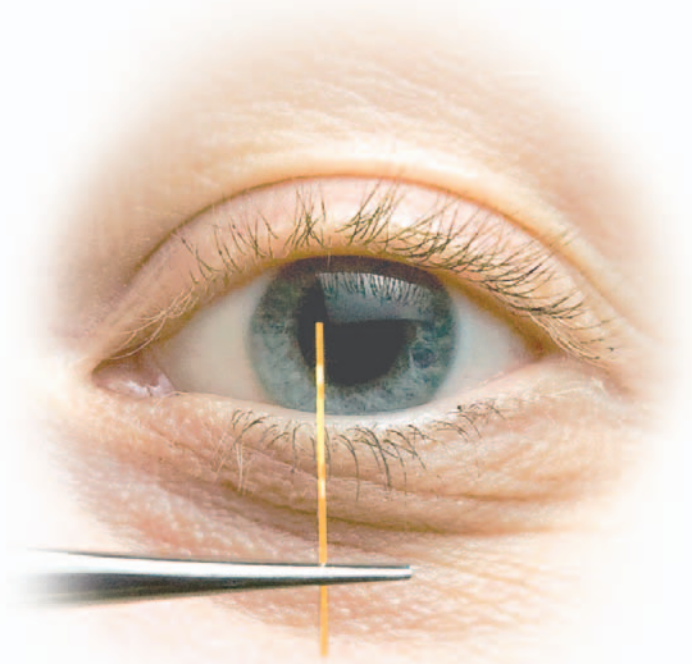
With the microcoil, the smaller device is as accurate as the laboratory-scale spectrometer with its huge superconducting magnet and can analyze concentrated samples in volumes as small as a microliter or even a nanoliter (10^{-6} or 10^{-9} liters). To improve the portable device even more, the Livermore team is coupling it with capillary electrophoresis to provide concentrated samples that are separated for analysis. In the combined technique, the miniscule sample is added to a 360-micrometer capillary filled with a buffer



Microcoils for the portable NMR chemical sensor are made using a programmable laser lithographic method called LaserLathe, which was developed at Livermore. Microcoils made with this technique can be as small as 100 micrometers in diameter.



Livermore physicist Kristl Adams holds the completed probe assembly for the portable NMR sensor. The probe, which contains the sample capillary inside a larger microcoil-wrapped capillary, is inserted into the permanent magnet for sample analysis.



Livermore physicist Julie Herberg holds a microcoil through which a chemical passes for NMR analysis. The miniaturized coil makes the portable NMR system feasible.

solution. The capillary ends are placed in the buffer, and a voltage is applied. Electrophoresis then separates the chemical species based on the different molecules' size and charge.

"We use a capillary within a capillary," says Herberg. "This setup allows a responder in the field to easily replace the inner capillary should it clog or break. The design also provides continuous current across the capillary for good electrophoresis separations."

Conundrums to Solve

Although the system is transportable and functioning, the team is still working to improve the device. One concern is that the electrophoresis current distorts the NMR signal. The team's

solution is to stop the voltage during NMR acquisitions, in other words, to apply voltage only between scans.

Another issue is balancing NMR sensitivity and electrophoresis resolution. For optimal NMR, the higher the sample concentration is, the higher the spectrometer's sensitivity will be. But capillary electrophoresis requires very small samples and lower concentrations, in the parts-per-million range. Using a capillary with a large inner diameter allows more sample into the coil volume, which will increase NMR sensitivity but can result in less homogeneity from the magnetic field and the coil itself. A capillary with a smaller internal diameter combined with high voltage and small sample size results in the best electrophoresis resolution but decreases the NMR detection limit.

Yet another challenge is that the field strength of the device's permanent magnet fluctuates with temperature. "If samples are of low concentration, we want to scan for a long time to increase the nuclear resonance signal-to-noise ratio," says Herberg. But in an environment with changing temperature, scans extended over a long period will produce smeared images that are difficult to interpret. "We are evaluating materials that are more temperature stable for our portable magnets," says Herberg. In addition, the team is applying a predictive model to increase detection capabilities by taking shorter scans, limiting temperature shifts, and combining scanned images to reveal spectra that were not clear before.

Even with these challenges remaining, the team has made considerable progress. And the briefcase-size NMR device offers many advantages. "Our portable system is inexpensive and robust," says Herberg, "important factors that will make it available to more users and improve its reliability in the field."

—Katie Walter

Key Words: chemical warfare agent, electrophoresis, LaserLathe, nuclear magnetic resonance (NMR) spectrometry.

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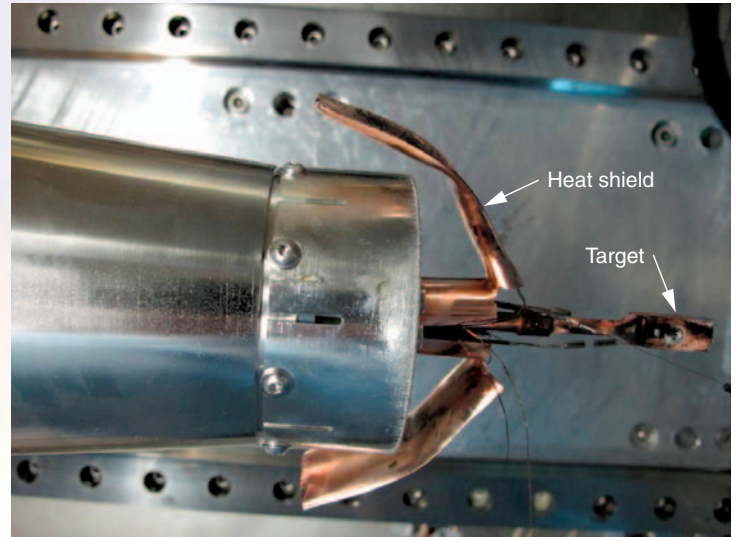
Targets Designed for Ignition

AS the world's population continues to grow at a brisk pace, more and more people aspire to the lifestyle and energy consumption levels of industrialized countries. The world's energy needs are increasing rapidly, but supplies of the most convenient forms of fuel are finite. Commercial fusion power has the potential to fill the gap between supply and demand by providing an affordable, virtually limitless source of energy. But first, the technology must pass an important test: demonstrating that self-sustaining fusion reactions can be achieved and reproduced in the laboratory.

Research teams worldwide have been working on this science and engineering grand challenge for decades. Experiments at the National Ignition Facility (NIF), the world's largest, most energetic laser, are the next major step toward making fusion a viable energy source. In 2009, a multidisciplinary team of scientists from Lawrence Livermore and its partners on the National Ignition Campaign (NIC)—Los Alamos and Sandia national laboratories, the Laboratory for Laser Energetics at the University of Rochester, General Atomics, Massachusetts Institute of Technology, Commissariat à l'Énergie Atomique in France, and Atomic Weapons Establishment in the United Kingdom—conducted a series of NIF experiments to validate and optimize the target design for upcoming ignition experiments. These hohlraum energetics shots, together with laser commissioning (see *S&TR*, April/May 2010, pp. 4–11) and fueling targets with tritium, are the final pieces needed to demonstrate that the giant laser is ready for the first credible ignition experiments.

NIF experiments are designed to achieve ignition through indirect-drive, inertial-confinement fusion. Rather than directing laser beams to hit a target for direct-drive ignition, NIF's 192 beams are focused through a hole in the top and bottom of a gas-filled, gold hohlraum—a centimeter-size enclosure that traps radiation. In the center of the hohlraum is a 2-millimeter-diameter pellet filled with nuclear fuel in both gas and solid forms. (See *S&TR*, July/August 2007, pp. 12–19.) During a shot, laser beams strike the internal walls of the cryogenically cooled hohlraum and are converted to x rays that irradiate and heat the outer layer of the fuel pellet. As this layer expands and ablates, it rapidly compresses the pellet's core, driving it to temperatures and pressures greater than those in the interior of the Sun. These extreme conditions cause the fuel's nuclei to fuse and release far more energy than was necessary to initiate the reaction.

The NIC team divided the hohlraum shot series, a precursor to ignition attempts, into three sets that progressively scale up



A postshot photograph of a bent heat shield surrounding a spent target illustrates the energy concentrated on the target during a hohlraum energetics experiment at the National Ignition Facility (NIF).

the complexity, laser power, and hohlraum size of experiments. In the first set, researchers activated 20 major optical, x-ray, and neutron diagnostic instruments, which together provide more than 200 streams of data for every experiment. The goal for the first sequence was to assess diagnostic performance, so the hohlraums in these 24 shots were either empty or filled with gas and kept at room temperature.

Once the diagnostics were brought on-line, the experimenters could gather data in subsequent shots to determine whether the hohlraum produces the environment needed for ignition. The second shot sequence focused on cryogenics and the third on hohlraum energetics. These 45 shots used hohlraums cooled to -253°C , similar to the anticipated ignition targets but with dummy capsules. In the cryogenics series, researchers assessed whether the hohlraum could be kept at the optimum temperature for fuel capsule performance and whether mechanical components associated with target cooling would cause undesirable laser light reflections. The energetics sequence examined the x-ray environment within the hohlraum to ensure that each shot would achieve the required temperature and symmetry.

Even Small Targets Provide Grand Data

The first experiments in the energetics series were conducted with scaled-down targets and laser energies ranging from 500 to 800 kilojoules, lower than researchers expect to use for ignition. The series culminated in a 1-megajoule shot on a full-scale, 1-centimeter-long hohlraum. After analyzing results from these shots, the NIC team now predicts that 1.2 to 1.3 megajoules of energy must be delivered to the target for successful fusion experiments. According

to Livermore physicist Siegfried Glenzer, conducting the early portion of the campaign with lower energies and smaller targets was prudent. By scaling the energy and hohlraum size, researchers can obtain important information on hohlraum physics and make relevant measurements while minimizing risk.

“We want to be good stewards and not damage the facility if something unexpected happened,” says Glenzer, who led the energetics experiments. “Our team worked hard to make the most of these experiments. The quality of each shot was outstanding, and we tried to learn the maximum amount on every one. The results gave us confidence that we’re making strides toward getting the right hohlraum with the right performance for ignition.”

Limiting Escaped Light

One uncertainty that the NIC team set out to resolve is whether laser–plasma interactions in the hohlraum would sap enough energy to thwart pellet fuel compression. These interactions could cause laser light to scatter away from the hohlraum, a process that is difficult to model and thus predict accurately.

“Backscatter can reflect a substantial amount of laser light, which reduces the energy that is coupled to the target in the first place,” says Glenzer. “It can also accelerate electrons in a plasma, causing the capsule to preheat and making it harder to compress.” A gas of charged particles, plasma is an inevitable result of the extreme temperatures and pressures within the hohlraum. However, if the plasma redirects valuable energy away from the fuel pellet, it interferes with the creation of the uniform x-ray field needed to evenly compress the target.

Livermore’s Nathan Meezan, lead target designer for the energetics shot series, says, “Laser–plasma interactions were a major consideration when designing the experiments.” And the results yielded surprising information about backscatter. In room-temperature shots on hohlraums filled with pentane gas—control shots, of a sort—very little backscatter occurred. The physicists then switched to a mixture of 80 percent helium and 20 percent hydrogen, two gases that do not freeze at cryogenic temperatures. Previous experiments with the OMEGA laser at the Laboratory for Laser Energetics indicated that this mixture would dampen a type of backscatter known as stimulated Brillouin scattering. But on the NIF shots, the helium–hydrogen combination produced significant Raman backscattering, an unexpected effect.

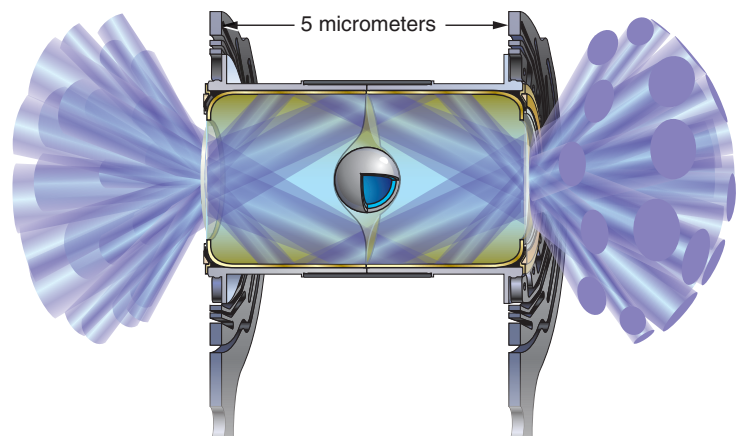
Calculations made by Livermore physicist Denise Hinkel showed that a pure helium gas fill would reduce Raman scattering. To test that prediction, the NIC team filled a fuel capsule with 100 percent helium but made no other changes to the target. The Raman backscatter decreased by more than a factor of two. Stimulated Brillouin scattering turned out to be of little concern for this target design. In fact, overall, the plasma did not cause as much interference as projected. On subsequent shots, less than 5 percent of energy was lost because of backscatter.

Results throughout the energetics shot series were even better than scientists had predicted. Data consistently agreed with previous computer models and calculations. Because of NIF’s reliability and flexibility, the cryogenics experiments went smoothly. In earlier experiments with lasers such as OMEGA and Nova (the Laboratory’s predecessor to NIF), obtaining consistent results and reliable data on this type of experiment was a challenge. With NIF, the cryogenic hohlraums heated almost as effectively as empty targets.

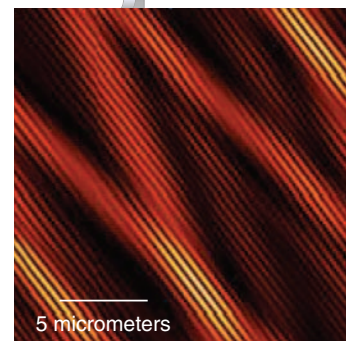
Another surprise finding was that simpler materials seemed to work as well as or better than combinations of materials. Just as helium proved to be a better hohlraum gas than the helium–hydrogen mixture, a hohlraum lined with gold performed as well as one with a more complex gold–boron lining. Because each NIF shot is such an elaborate enterprise, physicists welcome even minor reductions in complexity.

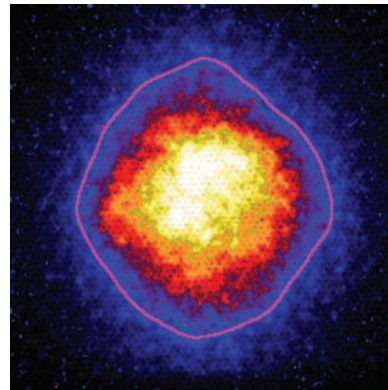
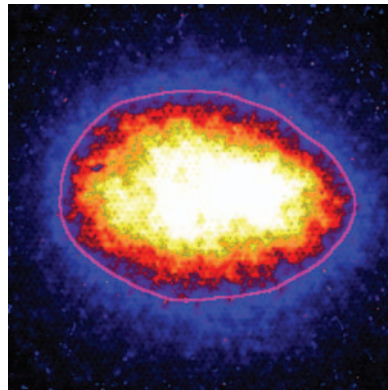
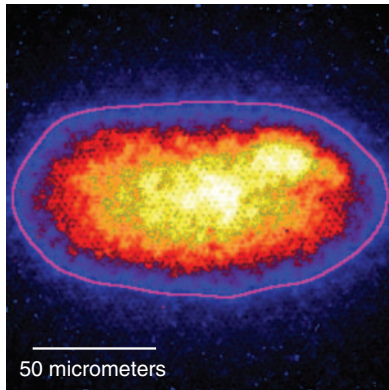
Tuning Beams to Balance Power

Implosion by nature is an unstable process. To improve the chances for success at creating fusion, scientists work diligently to make the conditions as precise and consistent as possible. For example, the fuel capsule must absorb energy in an even and controlled fashion to create a symmetric compression. With NIF, laser beams enter through holes in the top and bottom of the hohlraum and form two “cones.” The outer cone shines laser



(above) In this cutaway drawing, NIF’s 192 laser beams enter holes on both sides of the hohlraum and strike its inner walls, forming an x-ray field that heats the fuel capsule at the center. (right) Results from a NIF experiment show the laser beams intersecting at a hohlraum entrance hole. This region is a key area in tuning laser light to achieve symmetric compression.





X-ray emission images from a NIF shot demonstrate how wavelength tuning transforms compression, changing the fuel capsule from a pancake shape to a sphere that is much more symmetric.

light on the wall near the capsule's two poles, and the inner cone shines light near the capsule's equator. (See *S&TR*, July/August 1999, pp. 4–11.)

Early results from the energetics shots indicated that the capsule was compressed into a pancake shape, rather than a uniformly round sphere. That is, less energy reached the equatorial regions of the pellet than the top and bottom, likely because light was scattering within the hohlraum. The inner cone needed more power to make up for scattering losses and avoid a pancake shape. Shifting the power balance of the two cones required changing the color, or wavelength, of beams forming the outer cone. Glenzer explains, "By changing the wavelengths of laser light, we can control where the light goes."

This new technique, called wavelength tuning, had been calculated a year earlier by Livermore physicist Pierre Michel. It uses the grating effect that occurs when the overlapping beams forming the inner and outer cones enter the hohlraum and interact with the plasma they create. Tuning these beams with respect to one another controls the power distribution in the hohlraum because the grating effect redirects light, just as a prism splits and redirects sunlight according to its wavelength.

With this technique, says Meezan, "The laser can deliver a lot more power to part of the hohlraum without having to increase production." In fact, it delivered at least 25 percent more power to the inner cone and effectively redistributed power after beams left the laser. This sort of precision tuning is possible because of NIF's flexibility and allows shot designers to make the most efficient use of the available beam energy.

Fusing It All Together

Glenzer and Meezan both note that an exciting aspect of the energetics shot series was bringing together so many aspects of ignition experiments for the first time. The shorter pulses and lower power levels on the OMEGA laser simply cannot match those of NIF. With NIF, researchers can study all the vital aspects of laser and target physics in the same experiment. "Even the wavelength tuning is enabled by NIF's scale," says Glenzer. He

adds that combining NIF's long, plasma-producing pulses with larger hohlraum designs made this effect possible.

The NIC team continues to refine the hohlraum design and performance. To reach the peak radiation temperatures of 300 electronvolts, or more than 3 million kelvins, required for ignition, researchers must still pair a slightly larger hohlraum with somewhat higher energy levels. So far, shots have peaked at 285 electronvolts. NIC scientists must also prove that they can achieve the necessary symmetry to compress the fuel capsule by about double the amount achieved to date. Upcoming experiments will test ignition-sized hohlraums and target capsules filled with ignition fuel. Additional neutron diagnostics will be activated as well to examine the physical processes occurring inside the capsule.

Excitement and expectations continue to build throughout the fusion energy community worldwide as the NIC team releases results from the energetics shot series. The management team at the Laboratory's NIF and Photon Science Principal Directorate has seen a marked increase in applications from other research organizations proposing experiments at the Livermore facility. And the shot series has already inspired the first set of astrophysical experiments on NIF, using the hohlraum designed for the energetics sequence. Thanks to a team effort and spectacular results, NIC scientists are gaining confidence that they can meet the NIC challenge—producing the implosion conditions needed to drive ignition.

—Rose Hansen

Key Words: Brillouin scattering, cryogenics, energetics, fuel capsule, hohlraum, inertial confinement fusion, laser–plasma interaction, National Ignition Campaign (NIC), National Ignition Facility (NIF), Raman scattering, target design.

For further information contact Trish Damkroger (925) 422-5816 (damkroger1@llnl.gov).

Patents

Apparatus for Stopping a Vehicle

Willard H. Wattenburg, David B. McCallen

U.S. Patent 7,631,950 B2

December 15, 2009

This apparatus externally controls the brakes on a vehicle equipped with a pressurized fluid braking system. It can include a pressurizable vessel that is adapted for fluid-tight coupling to the braking system. The device is activated by one of three techniques: hitting the rear of the vehicle with a pursuit vehicle, shooting a target mounted on the vehicle, or sending a signal from a remote control. These techniques modify the fluid pressures in the vehicle's braking system to stop the vehicle and temporarily render it inoperable. A control device placed in the driver's compartment can also render the vehicle inoperable and cannot be disabled by a driver or hijacker.

Material for Electrodes of Low Temperature Plasma Generators

Malcolm Caplan, Sergel Evgeévich Vinogradov, Valeri Vasilévich Ribin, Valentin Ivanovich Shekalov, Philip Grigorévich Rutberg, Alexi Anatolévich Safronov, Vasili Nikolaevich Shiryayev

U.S. Patent 7,671,523 B2

March 2, 2010

A material designed to produce electrodes in low-temperature plasma generators contains a porous metal matrix filled with a material that emits electrons. A mixture of copper and iron powders forms the porous metal matrix, which is combined with a Group IIIB metal component such as yttrium oxide (Y_2O_3) in various proportions, for example: iron from 3 to 30 percent by mass, Y_2O_3 from 0.05 to 1 percent, and copper the remainder. Copper provides a high level of heat conduction and electric conductance. Iron decreases the intensity of copper evaporation as plasma is created, which increases the material's strength and lifetime.

Yttrium oxide decreases the electronic work function and stabilizes arc burning. Low-temperature, alternating-current plasma generators are used to decontaminate low-level radioactive wastes and to destroy liquid organic, medical, and municipal wastes; chemical weapons; toxic warfare agents; and other toxic materials.

Area X-Ray or UV Camera System for High-Intensity Beams

Henry N. Chapman, Sasa Bajt, Eberhard A. Spiller, Stefan Hau-Riege, Stefano Marchesini

U.S. Patent 7,672,430 B2

March 2, 2010

This system includes a source for directing a beam of radiation at a sample. A multilayer mirror oriented at an angle less than 90 degrees from the beam's axis reflects at least part of the radiation after the x-ray or ultraviolet (UV) beam hits a sample. A pixilated detector then measures the reflected radiation. In another setup, when a beam is directed at a sample, at least some of the radiation diffracted by the sample is reflected. Most of the radiation not diffracted by the sample is not reflected. Some of the reflected radiation is again detected. A third setup directs a radiation beam at a sample, a multilayer mirror reflects some of the radiation diffracted by the sample, and some of this reflected radiation is detected.

Electrical Initiation of an Energetic Nanolaminate Film

Joseph W. Tringe, Alexander E. Gash, Troy W. Barbee, Jr.

U.S. Patent 7,687,746 B2

March 30, 2010

In this heating apparatus, an energetic nanolaminate film produces heat when initiated. A control mechanism on the device directs electric current to the energetic nanolaminate film and, through the process of joule heating, increases the film's temperature as specified for initiation.

Awards

Rick Ryerson, a group leader in the Atmospheric, Earth, and Energy Division of Livermore's Physical and Life Sciences Directorate, has been elected a **fellow** of the **U.S. Geochemical Society** and the **European Association for Geochemistry**. The two societies jointly award this title to outstanding scientists who over the years have made a major contribution to the field of geochemistry. Ryerson becomes the first Laboratory scientist to receive this award, which is given to no more than 10 scientists each year. His recent work includes mineral–fluid–melt equilibria and diffusion kinetics in Earth's interior, focusing on geochemical applications of high-spatial-resolution, secondary-ion mass spectrometry.

Ray Beach, a physicist in the Laboratory's National Ignition Facility and Photon Science Principal Directorate, has been selected as a **fellow** by the international optics and photonics society **SPIE**. One of 62 fellows named this year, Beach was honored for his work in developing high-average-power diode-pumped lasers. Each year, SPIE promotes members to the rank of fellow in honor of their technical achievement and their service to the general optics community and to SPIE in particular.

Diamonds Put the Pressure on Materials

Since the mid-1990s, Livermore scientists have used diamond anvil cells (DACs) to compress microgram-size samples under extreme pressures. Now, with the Laboratory's new dynamic DAC (dDAC), researchers can control how quickly a material is compressed and thus study whether different loading rates affect a material's microstructure and state. Another new device, called the moissanite anvil cell (MAC), can accommodate samples as large as 3 millimeters in diameter during high-pressure experiments. Because of their size, MACs are better suited than traditional DACs or dDACs for testing materials that are difficult to handle in microscopic sizes, such as plutonium. Lawrence Livermore is also a member institution of the Department of Energy-funded High Pressure Collaborative Access Team facility located at Argonne National Laboratory's Advanced Photon Source. Because this light source produces x rays with very high brilliance, scientists can rapidly collect data from small samples under pressure, allowing them to study phase transformations and the properties of materials over a broad range of pressures and temperatures.

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Ensuring Confidence in U.S. Nuclear Weapons



Scientists combine materials research, experiments, and simulations to anticipate potential issues in aging nuclear weapons.

Also in July/August

- In climate modeling and other fields, understanding uncertainty, or margin of error, is critical.
- Laboratory experiments reveal the pathogenesis of Tularemia in host cells, bringing scientists closer to developing a vaccine for this debilitating disease.
- Livermore scientists are at the forefront of a remediation and resettlement effort on Rongelap Atoll in the Marshall Islands.

Coming Next Issue

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